Mode-Locked Femtosecond Titanium:Sapphire Laser

Model Trestles – 50F

DEL MAR PHOTONICS

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1. INTRODUCTION

TITANIUM-DOPED SAPPHIRE

Titanium-doped sapphire (Ti:Sapphire) is a solid state laser medium capable of tunable laser operation over broad range of near infrared (IR) wave lengths. Because of its broad absorption band in blue and green, energy for lasing process can be supplied by standard continuous wave (CW) argon ion laser or CW 532 nm, high-power, diode-pumped solid state laser as opposed to an electrical discharge or flash lamp that supplies broad band excitation.

With properly chosen optics, the Ti:Sapphire laser delivers a range of wave lengths from 690 nm to 1080 nm, and pulse durations < 20 fs.

Solid-state mode-locked lasers produce femtosecond light pulses using Kerr lens mode-locking (KLM) principle of operation and continuous wave pumping sources. KLM principle combines self-focusing nonlinear optical effect and aperture effect together to reach the shortest optical pulses. This Kerr self-focusing effect leads to slight changes in the spatial intensity profile of the resonator mode in laser oscillators. As a consequence, by introducing an intracavity aperture, a power-dependent loss can be created. Owing to the quasi-instantaneous response of nonresonant Kerr nonlinearities, the amplitude modulation induced by self-focusing is able to simulate ultrafast saturable-absorber action and support pulse formation down to the femtosecond regime in solid-state lasers that have long gain-relaxation times. The gain bandwidth of solid state laser materials such as Ti:Sapphire extends over >200nm and has the potential for supporting pulses of less than 10fs. The pulse duration from these lasers is determined by critical interplay between intracavity self-phase modulation in media, and negative group delay dispersion.

Trestles-50F femtosecond laser head contains the Ti:Sapphire rod and the optics that form the resonator cavity.

Del Mar Photonics guarantees that provided laser was tested and it is suitable for the Kerr lens mode-locked operation. On the one hand, the laser installation without the help of the manufacturer requires some experience of the user in laser physics. But on the other hand, by working with our laser you will gain experience in ultrafast laser technology.

2. LASER SAFETY

Trestles-50F and its pump laser are Class IV –high-power lasers, whose beams are, by definition, safety and fire hazards. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as secular reflections cause severe skin or eye damage.

Trestles-50F laser emits CW and pulsed infrared radiation; it is extremely dangerous to the eye. Infrared radiation passes easily through the cornea, which focuses it on the retina, where it can cause instantaneous permanent damage.

SAFETY PRECAUTIONS

- Wear protective eyewear at all times; selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear vendors are listed in the *Laser Focus World, Laser Optronics, and Photonics Spectra* buyer's guides. Please use safety instructions of your pump laser and follow their recommendations in your work.
- Maintain a high ambient light level in the laser operation area. This keeps the pupil constricted, thus reducing the possibility of eye damage
- Keep the protective cover on the laser at all times.
- Avoid looking at the output beam; even diffuse reflections are hazardous. Keep all beams below eye level always. Never look in the plane of propagation of the beams.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.

- Use an infrared detector or energy detector to verify that the laser beam is off before working in front of the laser.
- Operate the laser at lowest beam intensity possible, given the requirements of the application.
- Expand the beam whenever possible to reduce beam power density.
- Avoid blocking the output beams or its reflection with any part of the body.
- Establish a controlled access area for laser operation. Limit to those trained in the principles of laser safety.
- Post prominent warning signs near the laser operation area (Figure.1).

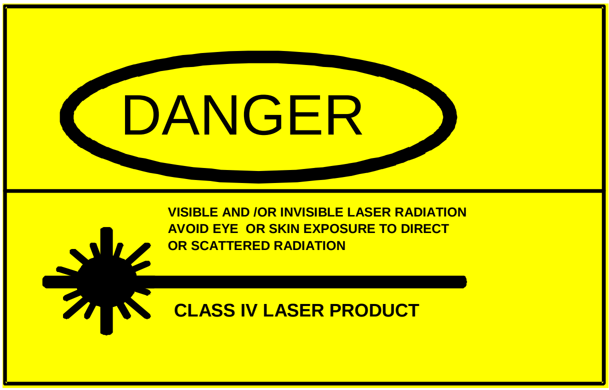


Figure 1. Standard safety warning sign

- Provide enclosures for beam paths whenever possible.
- Set up shields for secular reflections.
- Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering.

Be very careful while executing any step of the alignment. Avoid any exposure to the direct and reflected laser beams. Direct and reflected laser radiation from pump laser and Ti:Sapphire laser can cause serious eye damage. Remember that Ti:Sapphire radiation is invisible or looks like red laser radiation of low intensity. However, it is dangerous even at lowest intensity. Intense incoherent luminescence is emitted from the Ti:Sapphire rod also.

We recommend using protective boxes covering all elements outside of the Ti:Sapphire laser.

Follow the instructions listed in this manual for safe operation of your laser.

3. Laser description

GENERAL OVERVIEW

The Trestles-50F laser head contains the Ti:Sapphire rod and optics that form the oscillator cavity. Elements include pump beam mirrors, laser rod, focusing lens and mirrors, and output coupler (OC), high reflectors (HR), beam folding mirrors, prisms as dispersion control elements and slit as spectral turning element.

Connections to the laser include cooling water, power and control from “Electronics Module” and power and slit driver module (optionally).

Option:
The Electronics module enclosed with the laser consists of the pulse detection circuit and driver circuits for electromechanical starter. All indicators and controls are located on the front and upper panel. One cable connects it to laser head, the other pump cable and BNC cable may be connected to customer’s oscilloscope.
Slit driver module enclosed with the laser consists of circuits for moving slit and prism in side the laser head.

For continuous-wave (CW) pumping, there is one basic requirement for lasing action: the unsaturated round-trip CW gain must exceed the round trip loss from all sources. The CW gain is obtained by having a high inversion density and an adequate length of Ti:Sapphire material. The high inversion density comes from having a high pump intensity and high Ti^{3+} ion concentration. Losses in the Ti:Sapphire laser come from losses in mirror coatings and polished surfaces, and what is more important, the residual loss in the Ti:Sapphire material itself. This loss is proportional to the rod length and varies with the Ti^{3+} concentration, generally increasing as the Ti^{3+} concentration increases.

Unlike a dye laser, the pump illumination in Ti:Sapphire laser must be collinear with the cavity mode over a relatively long length of laser rod. Continuous, high inversion density over the entire volume of a rod several millimeters in diameter is difficult to achieve. To circumvent this problem, the pump light is focused to a narrow line within the rod and the oscillating laser mode is similarly focused and overlapped within the same volume – a technique known as longitudinal pumping. The output beam is then collimated and expanded to normal size. The residual pump beam is dumped through the second cavity focus mirror.

PUMP LASER

Because of its broad absorption band in blue and green, energy for lasing process can be supplied by standard continuous wave (CW) argon ion laser or CW 532 nm, high-power, diode-pumped solid state lasers. It is very important to note that pump laser should work in TEM_{00} mode.

For pumping Trestles-50F laser a pump laser operating in TEM_{00} transverse mode regime with output power between 3 - 8 Watts should be used. Performance values given in this manual are based on using a 3-5 W pump beam unless otherwise noted. When using other than a 3-5 W pump, the output mirror should be changed. Please remember that stable operation of pump laser is the key for reaching good femtosecond operation of Ti:Sapphire laser. **TEM_{00} mode is very important.**

We recommend Spectra-Physics BeamLok™ argon laser operating in power mode, Spectra-Physics Millennia i/s Series lasers, Coherent Verdi Series, Laser Quantum Opus and Finesse Series.

THE FOLDED CAVITY

Del Mar Photonics modeled, analyzed and optimized the cavity design for optimum performance in minimal space. The result was a 8 mirror folded cavity (Figures 2 and 3). This scheme incorporates 8-mirror cavity (M1, M2, M3, M4, M9, M7, M8, OC), Ti:Sapphire crystal (TiS), lens for focusing of pump radiation (L), two prisms (P1 and P2) and slit (S).
Note: In some versions of the Trestles-50F the slit and p2 prism translations stages are combined on one translation unit.
In folded cavities where astigmatism is not eliminated, output beams are elliptical and hard to focus. But by carefully choosing the angles of the cavity focus mirrors and rod length, astigmatism in Trestles-50F output beam is virtually eliminated.

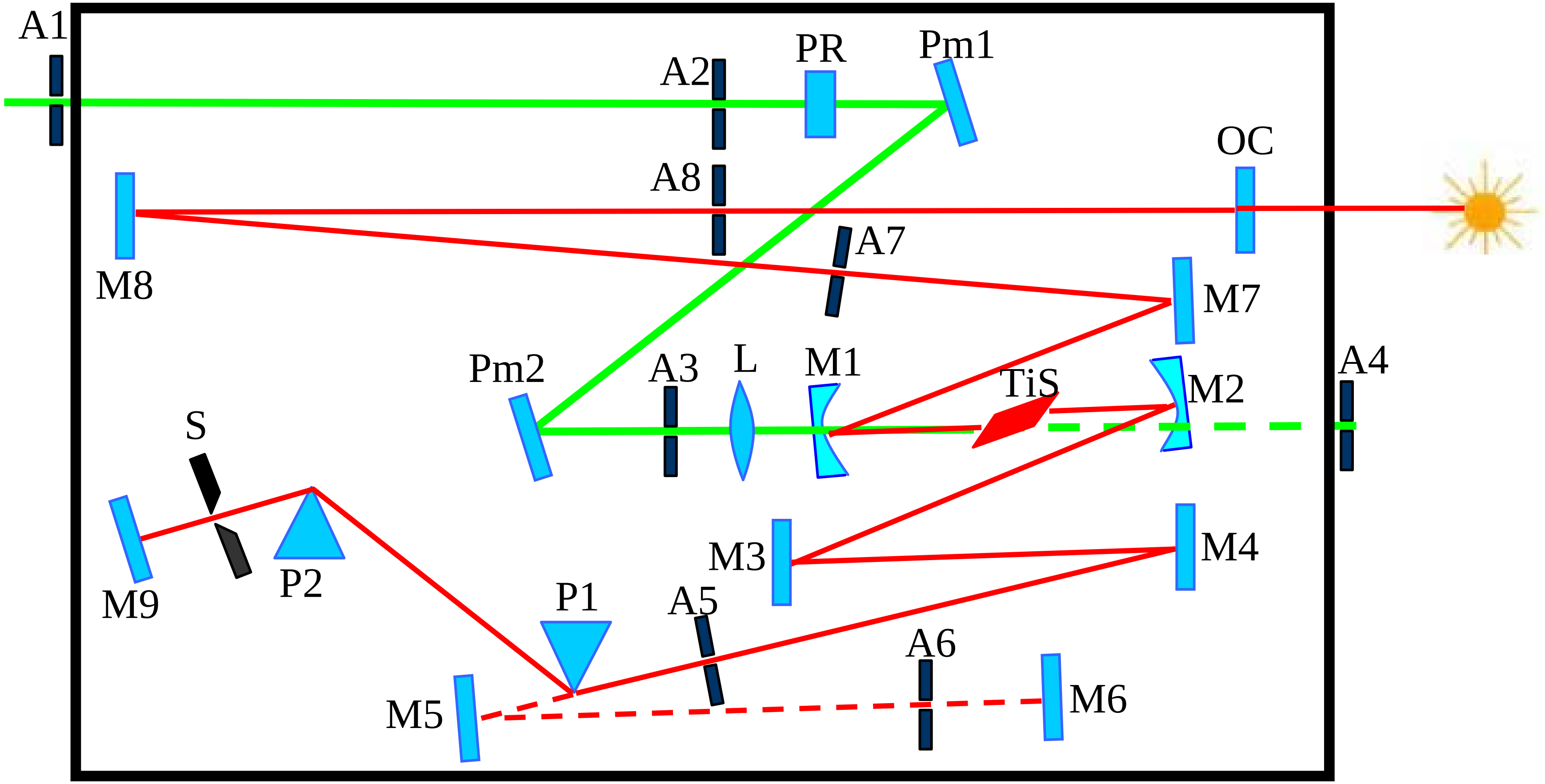


Figure 2. Basic Layout of Trestles-50F.

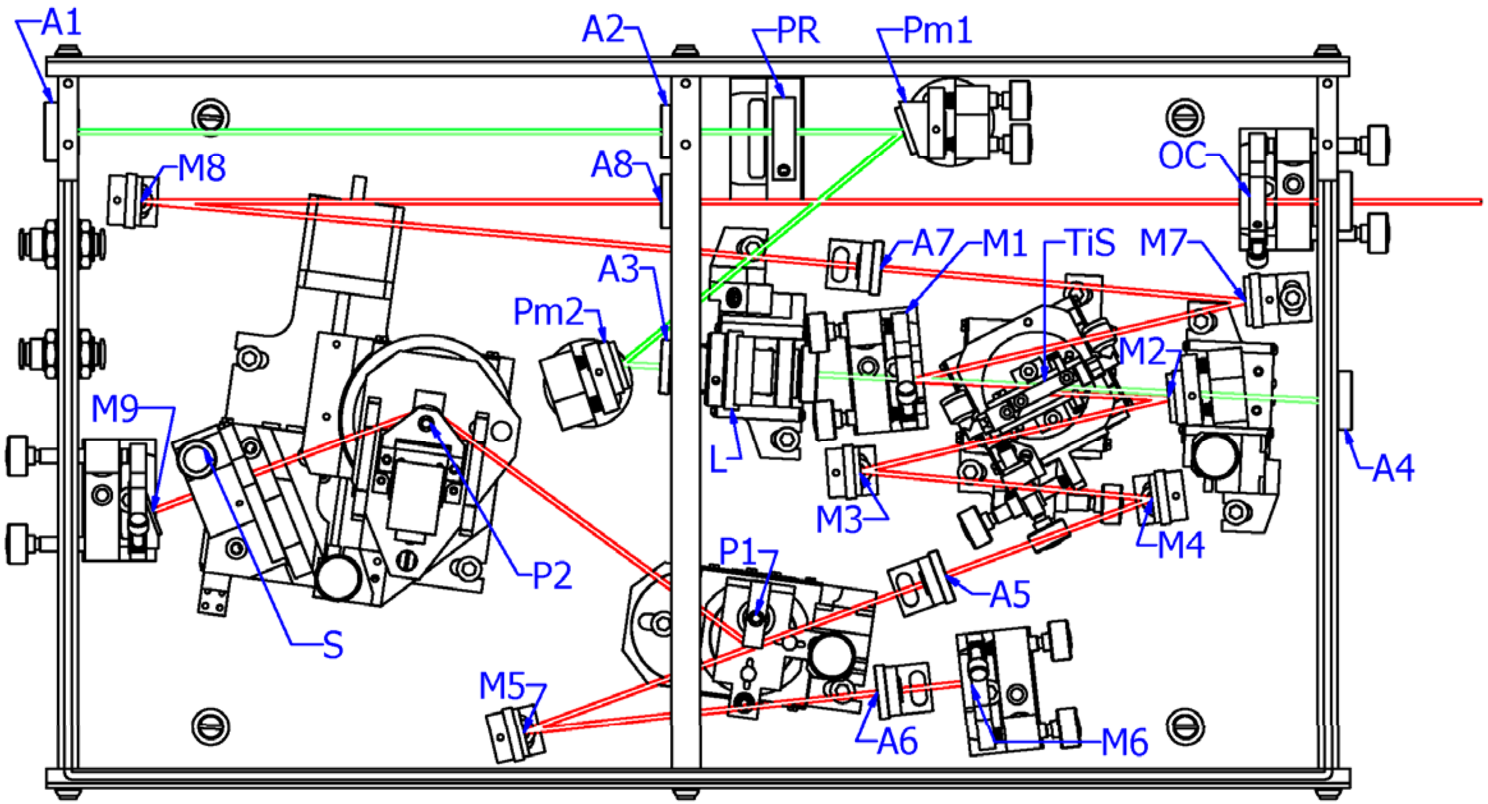


Figure 3. Schematic setup of Trestles-50F.

WAVELENGTH TURNING CHARACTERISTICS

Due to the Ti:Sapphire rod is birefringent, uninterrupted tuning is achieved when the c – axis of the rods is aligned coplanar with the polarization of the electric field within the cavity. Since the Ti:Sapphire rod and prism surfaces represent a total of six Brewster's angle surfaces, the polarization within the cavity is largely determined by the orientation of these surfaces. Furthermore, cavity losses are minimized and tuning is optimized when all these surfaces are accurately aligned at Brewster's angle. The Trestles-50F laser uses a proprietary Ti:Sapphire rod holder that orients the rod surfaces at Brewster's angle and allows the c axis of the rod to be aligned coplanar to the electric field vector. This technique compensates for unavoidable errors in rod orientation that occur when the rod is cut and polished. Wavelength tuning range of the Trestles-50F laser is 720 nm to 950 nm with two sets of optics (i.e. the rod and system are capable of continuous turning over this range). The laser comes with the optics set(s) you specified with your order.

WAVELENGTH SELECTION

The femtosecond Trestles-50F laser is wavelength tuned using a prism sequence and a slit. This sequence provides a region in the cavity where the wavelengths are spatially spread. A variable slit is located in this dispersed beam. The output wavelength is tuned by changing the position of the slit in the horizontal plane. The width of the slit can also be changed so that the bandwidth (and, hence, the temporal width) of the output pulse can be varied. This simple, straight-forward method covers the entire Ti:Sapphire range for ultrashort pulses.

PULSE WIDTH SELECTION

The pulse width tuning characteristics of the Ti:Sapphire laser are influenced by two factors: those inherent in the Ti: sapphire material itself and those from cavity parameters. While we cannot readily modify the Ti:Sapphire material to change pulse width, we can modify the net group velocity dispersion (GVD). The optical components in the laser cavity introduce positive GVD and cause pulse spreading. Further pulse spreading causes self-Phase modulation (SPM) in the Ti:Sapphire rod, which results from the interaction of the short optical pulse with the nonlinear refractive index. In order to obtain stable short output pulses, these effects must be compensated with negative GVD. Prism pairs are used to produce a net negative intracavity GVD in the femtosecond system. This allows the system to produce sub 100 fs near transform limited pulses over most of the wavelength regime.

DESCRIPTION OF COMPONETS

The scheme of Trestles-50F depicted in Figures 2 and 3 consists of the following optical elements for the basic configuration:

1. 5 mm long Ti-doped sapphire crystal (TiS).

2. Dielectric mirrors M1, M2, M3, M4, M5, M6, M7, M8, M9 with high reflection (>99,5%). M1, M2 – have high reflection for working wavelength and transparent for laser pumping radiation, radius of curvature is 100 mm; M3, M4, M5, M6, M7, M8, M9-high reflectors for working wavelength, flat mirrors; OC output coupler; Pm1, Pm2– pump routing flat mirrors.

3. L - lens for focusing of pumping radiation, focal length is F=80 mm.

4. P1, P2 - Brewster angle prisms at 800 nm.

5. PR – polarization rotator is used for changing the polarization of pump beam from vertical to horizontal.

6. A1, A2, A3, A4, A5, A6, A7, A8 – aligning apertures. A1, A2, A4, A8 is on the laser head walls, A3, A5, A6, A7 – are on aperture holder stages

We use mirrors M5, M6 in the process of alignment (see alignment procedure).

4. LIST OF ACCESSORIES

The following conditions or devices are required for assembling, testing and operation of a femtosecond Ti:Sapphire laser :

1. A pump laser operating in TEM_{00} transverse mode regime with output power 3-8 Watts. Please remember, that stable operation of the pump laser is the key point for achieving good femtosecond operation of Ti:Sapphire laser. **TEM_{00} mode is very important**.

2. Optical table. Ti:Sapphire laser itself requires about 0.5 m x 0.7 m area of the optical table. We recommend placing the pump laser and Ti:Sapphire laser on the same optical table for better stability.

3. Pump laser radiation should be horizontally polarized. If you have vertically polarized pump laser radiation, please use polarization rotator (PR).

4. A photodiode with >10 mm^2 sensitive area or low-inertial power meter for fast control of relative output power in the process of alignment.

5. Power meter for control of output power value.

6. Fast photodiode with 400 MHz oscilloscope to display the temporal structure of output radiation.

7. During aligning (full realigning of the laser) you may need two polarizers, we recommend polarization cubes or Glan laser prisms (PC1, PC2).

8. Interferometric autocorrelator for the measurement of pulse duration. Time resolution should be better than 10 fs.

9. A spectrometer operating near 800 nm for spectrum control. (We recommend using Del Mar spectrometer that is completely compatible with the Trestles-50F laser.)

10. Infrared sensor card for observation of weak IR luminescence.

11. For most stable operation of the laser use dry nitrogen gas to remove dust and water vapor from the laser head.

12. We recommend using a chiller to keep the Ti:Sapphire rod at a constant temperature for performance stability.

5. INSTALLATION

UNPACKING YOUR LASER

Your laser was packed with great care and all containers were inspected prior to shipment: the laser left Del Mar Photonics in good condition. Upon receipt of your laser, immediately inspect the outside of the shipping containers. If there is any visible damage to the container, make sure a representative of the carrier company is present when you unpack the laser.

Carefully inspect your laser as you unpack it. If you notice any damage, such as dents, scratches or broken knobs immediately notify the carrier and your Del Mar Photonics sales (sales@dmphotonics.com) representative.

Open the cover of the laser head and carefully remove bags covering the elements of laser and fixing elements which are used for transport. Carefully remove the bags, try not to misalign the laser, and damage mirrors during this procedure.

PLACEMENT OF TRESTLES-50F LASER HEAD

1. Turn on the pump laser according to its instruction manual and allow it to warm up.

2. Verify the output of the pump laser meets specifications for power and mode quality. (For pumping the Trestles-50F, the pump laser should be operating in TEM_{00} transverse mode regime with output power of >3 Watts.)

3. Reduce pump laser power to the minimum.

4. Close the pump shutter.

5. Place the Trestles-50F laser head on the table near the pump laser.

6. Hook up the water tubes to the laser head (Fig.4) and switch on cooling water (moderate water flow >=0.5 l/min).

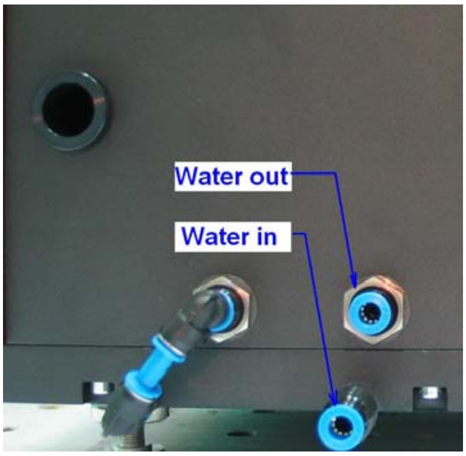


Figure 4. Water connectors

7. Adjust the heights of the pump laser and/or the Trestles-50F laser head so that the output beam of the pump laser is parallel to the table top surface and radiates at the same height as the center of the "pump window" on the Trestles-50F laser head.
   a) Adjust the height of the pump laser according to its user manual.
   b) Adjust the height of the Trestles-50F laser head:
      - Loosen the locking nut on each foot. The nuts are threaded onto each leg and jam against the bottom of the base plate to lock the foot in place and to add stiffness to the foot.
      - Wrench the foot to adjust the height so the center of input window is on the same height as the center of output window of pump laser above the table and parallel to the table top.
      - Tighten the locking nuts.

8. Secure the Trestles-50F laser head to the table with the four foot clamps provided.
   The clamps slide over the lower portion of each foot.
9. Verify the height adjust locking nuts on the feet are tight.
10. Connect the Starter button to the laser head (Fig. 5). Tap power supply into power line.

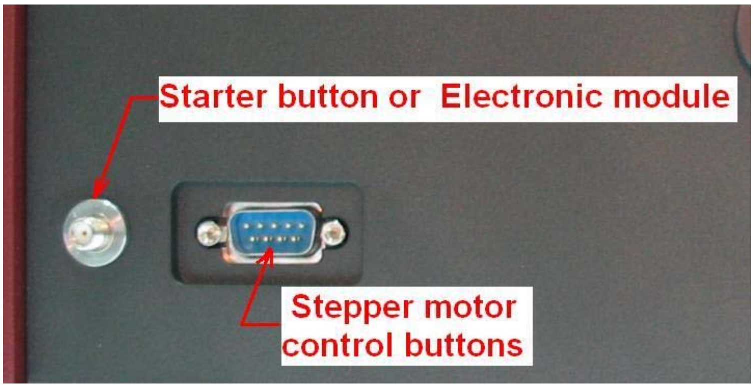


Figure 5.

11. Remove the pump window and screw in input aperture A1.

12. Use external routing mirrors to route the pump beam to the Trestles-50F laser head. *Please, pay attention to polarization changing when routing the pump laser beam.*
   - Open pump shutter.
   - Adjust the external routing mirrors only until the pump beam passes through the input aperture A1 and internal aperture A2. *Please, don't align the pump routing mirrors Pm1 Pm2 during this procedure*.
   - Close the pump shutter.

13. Optional: motorized slit and prism (Electronic starter):
   - *Connect the control buttons to the laser head (Fig. 5). Insert the power supply into power line. Detailed description of this device can be found on the CD with software for device.*
   - *Connect the Electronic module (Fig.5) to the laser head. Tap power supply in to power line. Detailed description of this device can be found in section 9 of the current manual.*

6. ALIGNMENT

This part of our instructions describes installation and alignment procedure for the Ti:Sapphire oscillator. Researchers use slightly different approaches to constructing a mode-locking Ti:Sapphire laser. If you have good experience in laser technology, you can use your own approach to the alignment of our femtosecond laser. Nevertheless, we hope that our instructions will help you in your work. Alignment procedure consists of two stages. **The first stage** is the alignment of continuous wave (CW) Ti:Sapphire laser. **The second stage** is the transformation of a standard CW configuration into a configuration suitable for mode-locking operation.

ALIGNMENT OF CONTINUOUS WAVE TI:SAPPHIRE LASER

The laser was factory aligned and under careful transportation conditions you can try to achieve the lasing without full laser realignment. It is not necessary to follow the italicized instructions. You should only carry out these procedures in case of complete laser misalignment under severe transportation conditions. In general, please follow the normally typed instructions.

1. Turn on the pump laser according to its instruction manual and allow it to warm up.

2. Reduce pump laser power to the minimum.

3. Remove the pump window and screw in the input aperture A1.

4. Using external routing mirrors direct the pump beam so that it passes through the input aperture A1 and passes through the apertures A2, A3 inside the Trestles-50F laser *(do not align Pm1, Pm2 mirrors for this aligning procedure, adjust only external routings mirrors. Pm1 and Pm2 should be already aligned for the beam to pass the A3)*

If routing mirrors are insufficient to align on the apertures use small adjustments of Pm1, Pm2 so that the pump beam passes through the apertures. Verify that beam passes through the centers of all 3 apertures.

5. Switch on cooling water *(moderate water flow ≥0.5 l/min)*.

6. If your pump laser is working in horizontal polarization then remove the polarization rotator (PR).

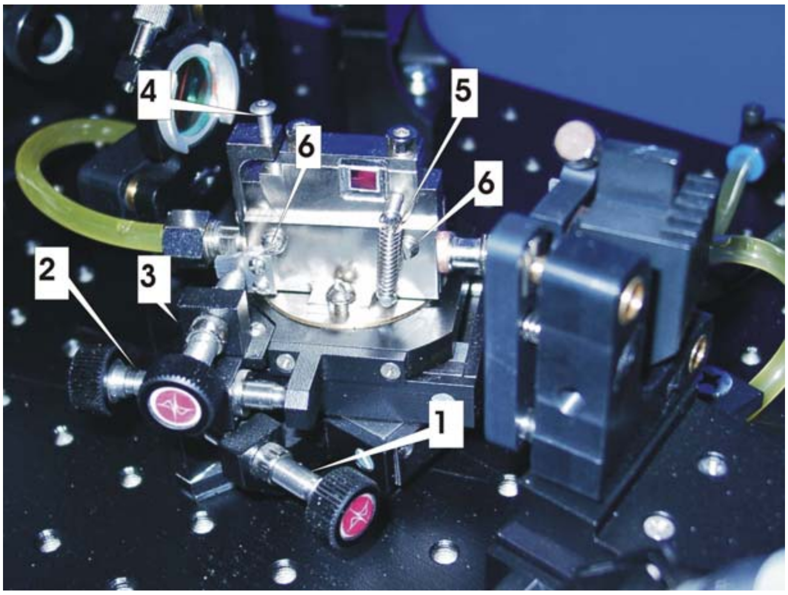
   If your pump laser is working in vertical polarization then adjust PR:
   - Loose the screw that clamps the PR mount to the tabletop.
   - Place the target to block the reflected beam from the first surface of the Ti:Sapphire crystal.
   - Rotate the PR mount around its vertical axis at small angle and find the position when the spot on the target has minimal brightness.
   - Verify that the pump beam is still passing through the center of PR. And passing through apertures A1- A3.
   - Tighten the screw that clamps the PR holder to the tabletop.

Again, the italicized instructions are only necessary if laser is completely misaligned. Follow non-italicized instructions ONLY the first time through.

7. Close the shutter of the pump laser.

8. Remove M1 and M2 mirrors with holders from their mounts.

9. Remove focusing lens L with the draw-tube from mount.



1. Screw for aligning crystal position on optical axis. 2. Screw for transverse aligning. 3. Screw for aligning Brewster angle. 4. Screw for aligning crystallographic axis orientation. 5. Spring
6. Fixing screw

Figure 6. Crystal Mount

10. Remove the crystal with the crystal holder (Figure 6).

- *Remove the two vertical springs from the holder using a metallic hook (metallic hook may be easily made from paper clip) or thin-flat-nose pliers.*
- *Remove the crystal with crystal holder.*

11. Open pump shutter.

12. Verify that the pump beam passes through the centers of A1, A2 and A3.

13. There is an etched line passing under the elements from Pm2 to M2.

14. Remove the beam stopper and screw in aperture A4.

15. Direct the pump beam so that it passes through the centers of all 4 apertures.

16. Install the focusing lens with draw-tube back to the lens mount.

17. *Verify that the center of the beam spot on aperture A4 is still on the center of A4.*

- *If the centers do not coincide in vertical plane then use the vertical lens adjusting screw to align the lens. (Some laser systems have lens holders without vertical aligning screw. If so then loosen, but do not remove, fixing screws (Fig.7). Align the position of the lens and then fix the screws.)*
- *If the centers are not coinciding in horizontal plane then loosen the screws that clamp the lens holding stage to the table top and move the translation stage in perpendicular to pump beam direction to align the lens.*
- *Verify that the center of the spot is not moving while you are moving the lens forwards and backwards holding in place the base of translation stage by hand. If the center of the spot is moving then rotate the stage (for example, if the center of the spot moved to the left side while the lens was moved closer to M1 then rotate the lens stage clockwise for a small angle), then align the centers by moving stage in perpendicular to pump beam direction to align the lens. Repeat this step until the center of the spot will not move and will coincide with center of A4 during lens translations along pump beam. Tighten the clamping screw.*

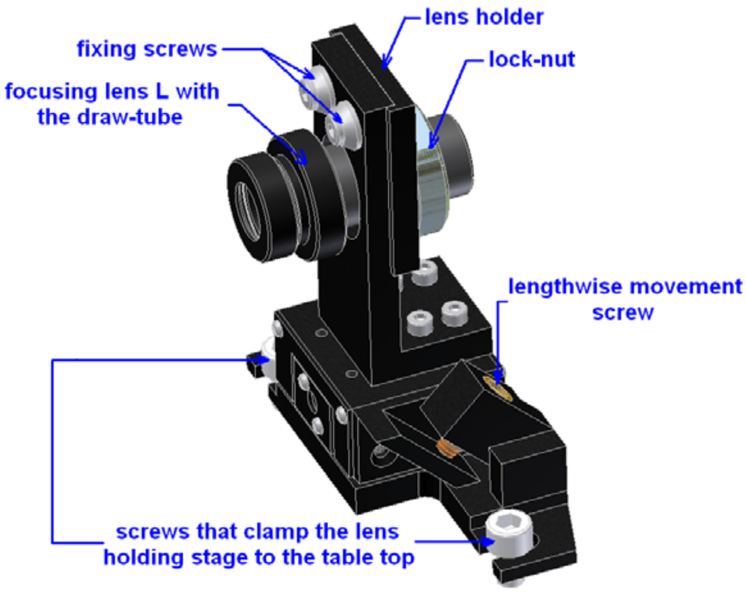


Figure 7. Lens Mount

18. *Close the pump beam shutter.*

19. *Install M1 mirror with the holder to its mount.*

20. *Insert the PC1 in the pump beam between the rotator and Pm2. Align it to transmit the horizontal polarization. (For polarizer cube follow this procedure. Open pump shutter. Adjust the PC1 so that the back reflected beam comes almost back to the pump laser (but not exactly), and side reflected beam is passing through the additional aperture (AA). AA is used to set the side reflected beam in resonator plane. Thus the polarization of the beam passing through is linearly polarized and polarization is horizontal.)*

21. *Remove A4.*

22. *Insert the second polarizer PC2 in the pump beam beyond the M2 mirror mount. Place the target (piece of paper) beyond PC2. Align the PC2 for a dark "field".*

23. *Install and align the crystal*

- *Close the pump shutter.*
- *Mount the crystal holder to its mount.*
- *Tighten two vertical springs.*
- *Open pump shutter.*
- *Verify that the beam is passing through the center of the crystal.*
- *Set up approximately Brewster angle by the angle control of crystal, observing green beam reflected from the Ti:Sapphire crystal entrance surface. Find position of crystal with minimum reflection.*
- *Align the crystal for a dark field on a target, rotating the crystal holder around the optical axis using the screw for aligning crystallographic axis orientation (see Figure 6).*
- *Close the pump shutter.*
- *Set up distance between M2 surface and entrance surface of the crystal to 48-49 mm by adjusting the longitudinal control screw on the crystal stage. Remove PC1 and PC2 with their mounts*

24. *Install M2 mirror with the holder to its mount. Set the distance between M1 and M2 surfaces to approximately 103-104 mm.*

25. *Remove aperture A4 and screw in the beam stopper beyond M2 mirror.*

26. Remove the blocker from aperture A6.

27. Open the pump shutter. Using insertion adjusting screw of the P1 prism, back the prism out of the beam path.

28. *Aligning M2 mirror, direct the residual part of pump beam to the center of the M3 mirror. Verify the height of the beam.*

29. *Aligning M3 mirror direct pump beam to the center of M4 mirror.*

30. *Aligning M4 mirror direct pump beam to the center of A5 and M5 mirror.*

31. *Aligning M5 mirror direct pump beam to the center of A6 and M6 mirror.*

32. *Aligning M6 direct beam back to the M5, M4, M3 and M2 mirror.*

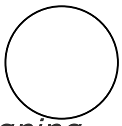
33. Unscrew apertures A1, A2, A5 and A6 leaving the aperture holders in place.

34. Increase the pump power up to 3-5 W. Use protective goggles for pump laser radiation.

35. *Aligning the positioning of the lens.* ***Use protective goggles for pump laser radiation during this procedure.*** *Remove beam blocker, beyond M2. Translating the lens to find the position when round shape of the pump beam will abruptly change to the oval shape. Re-insert the beam blocker.*

36. Use an IR card to see the luminescence near OC mirror.

\+ Reflection of M2-M3-M4-M5-M6-M5-M4-M3-M2-M1-M7-M8



Reflection of M1, M7 and M8 only.

37. *Aligning M1 mirror, direct luminescence reflected only from the M1 to the center of the M7.*

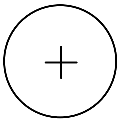
38. *Aligning M7 mirror, direct luminescence reflected from the M1, M7 to the center of the A7 and M8.*

39. *Aligning M8 mirror, direct luminescence reflected from the M1, M7 and M8 to the center of the A8 and OC.*

40. *Verify the height of the beam with the help of AA.*

Again, the italicized instructions are only necessary if laser is completely misaligned. If this is our first time through the alignment, be sure to follow the non italicized steps above (26, 27, 33, 34, 36).

41. Adjust the position of (+) spot by M6 controls. The spot should be approximately on the center of spot reflected from M1, M7 and M8 only.



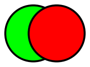
42. Align OC mirror so the reflected beam returns back to the center of A8, M8-A7 and M7.

43. Unscrew all apertures A1, A2, A3, A5, A6, A7 and A8 leaving the aperture holders in place .

44. If a correct alignment has been made, laser radiation should appear after small adjustments of M6 and OC. If not, then place the additional photodiode with large aperture beyond the OC mirror. The luminescence spot should be in the active area of photodiode. Adjust M6, OC and position of M2 mirrors for maximum signal until generation appears. Remove the photodiode.

45. Place the power meter into the output beam.

46. Adjust the M6 and OC for maximum output power. For optimization of Ti:Sapphire output power adjust OC and M6 by horizontal controls together and vertical controls together also. Output power should be close to the maximum when the spots on M1 look as in the picture below:

green  red

47. By small steps move M2 along the optical axis, try to find maximum output power. Make additional small adjustments using OC and M6 controls after each step.

48. Move the Ti:Sapphire crystal along the optical axis, try to find maximum output power. Make additional small adjustments using OC and M6 controls after each step.

49. Adjust Brewster angle using Ti:Sapphire crystal angle control in small steps. Try to reach maximum output power. Make additional horizontal adjustments using OC and M6 controls after each step.

50. Adjust focusing lens position and Ti:Sapphire crystal along the optical axis in small steps. Try to reach maximum output power. Make additional small adjustments using M6 and OC controls after each step.

51. Clean all mirrors in the cavity.
    - Close the pump shutter.
    - Clean one mirror by alcohol or acetone.
    - Open the pump shutter.
    - Verify the output power the value should be bigger or the same.
    - Make small adjustments of M6 and OC to maximize output power.
    - Repeat this procedure for mirrors in the cavity M1, M2, M3, M4, M5, M6, M7, M8, OC, Pm1, Pm2, and crystal surfaces.

52. Verify that Ti:Sapphire output power is not less than 10% - 15% of pumping power. If not, repeat steps 41-50. Sometimes, you should repeat these steps several times during the first alignment of the CW Ti:Sapphire laser. It requires patience.

53. Write down maximum output power and position of M2 micrometric screw. Move M2 forward and back and find positions of micrometric screw where Ti:Sapphire laser oscillation disappeared. Write down these positions. This is the range of stability.

Note. There are two ranges of stability in the asymmetric cavity (see G.Cerulla et. al., Opt.Lett. 19 (1994) 807).

54. Flip the slit aside.

55. Using adjusting screw of the P1 prism insert prism in the beam path. Slowly moving the prism into the beam you can find the position of the prism when laser oscillation begins between mirrors M6 – OC and small fraction of this generation is deviated by P1 prism.

56. Verify the correct aligning of the prism

- *Loosen but don't remove the rotation fixation screw R (Figure 8).*
- *Rotating the prism's base plate adjust prism for minimal deviation of the beam (Figure 9).*
- *The heights of the beams should be also 70 mm above the laser head table top. If it is necessary use the adjusting screws to align the prism (see Figure 8).*

57. Verify that the beam deviated by P1 strikes prism P2. Verify the height of the beam near P2.

58. Using the adjusting screw of the P2 prism insert prism in the beam path. Verify correct aligning of the prism in same manner as in 56*.*

Note. *If your laser was provided with an optional electro-mechanical starter, then P2 holder mounting is replaced by the electro-mechanical starter. Verify correct aligning of the prism in the same manner as in 56.*

59. Align M9 to return the beam deviated by P2 back through P2 and P1.

60. Insert P1 in the beam, by small adjustments of M9 mirror reach laser generation through the prisms. *Block M6 mirror by the blocker (aperture A5).*

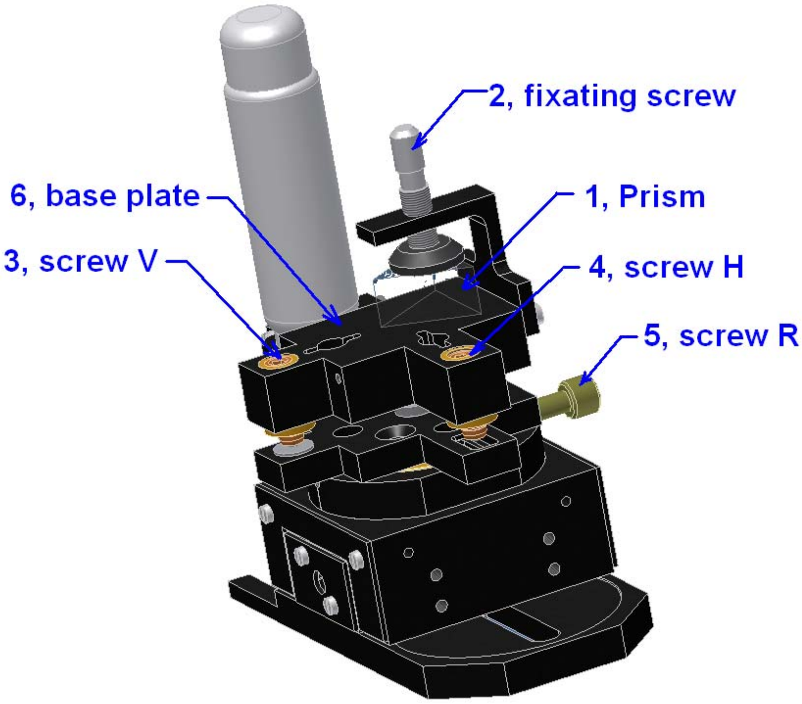


Figure 8. Schematic picture of prisms fixation and service

1 - prism
2 - fixating screw, ***!don't tighten it with force to prevent birefringence of prism!***
3 - screw **V** to align deviated beam in vertical plane,
4 - screw **H** to align reflected beams in vertical plane,
5 - screw **R** to fix rotation of base plate **6**,
6 - prism's base plate rotating by hand.

61. By aligning OC and M9 find maximum output power in same manner as in CW operation.

62. **Verify that the output power decreases not more than 15 percent lower then output power without prisms.** If it does, repeat the procedure from step 54. Sometimes, you should repeat it several times during the first alignment of the CW Ti:Sapphire laser. It requires patience.

Note. *After finishing this procedures there are some check points:*

1. *The spot on the M1 mirror should look like described in 46. If not align M9 and OC.*
2. *There are beams reflected from the apex of each prism. The beams should be almost parallel to each other and must be in resonator plane (plane at 70 mm above table top of the laser head). If not then align the prisms and M9, OC to fix it.*

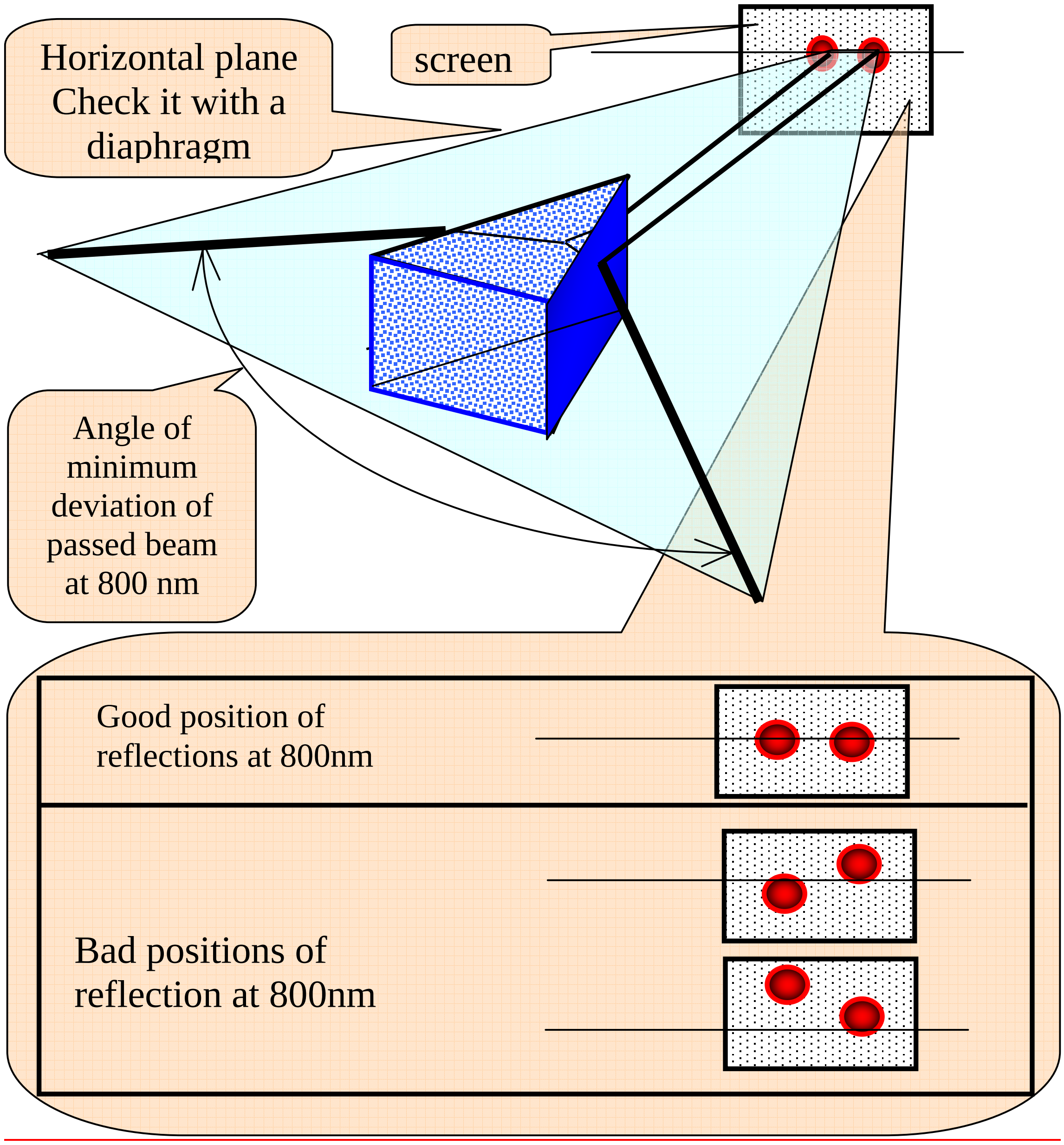


Figure 9. Prisms P1 (P2) alignment.

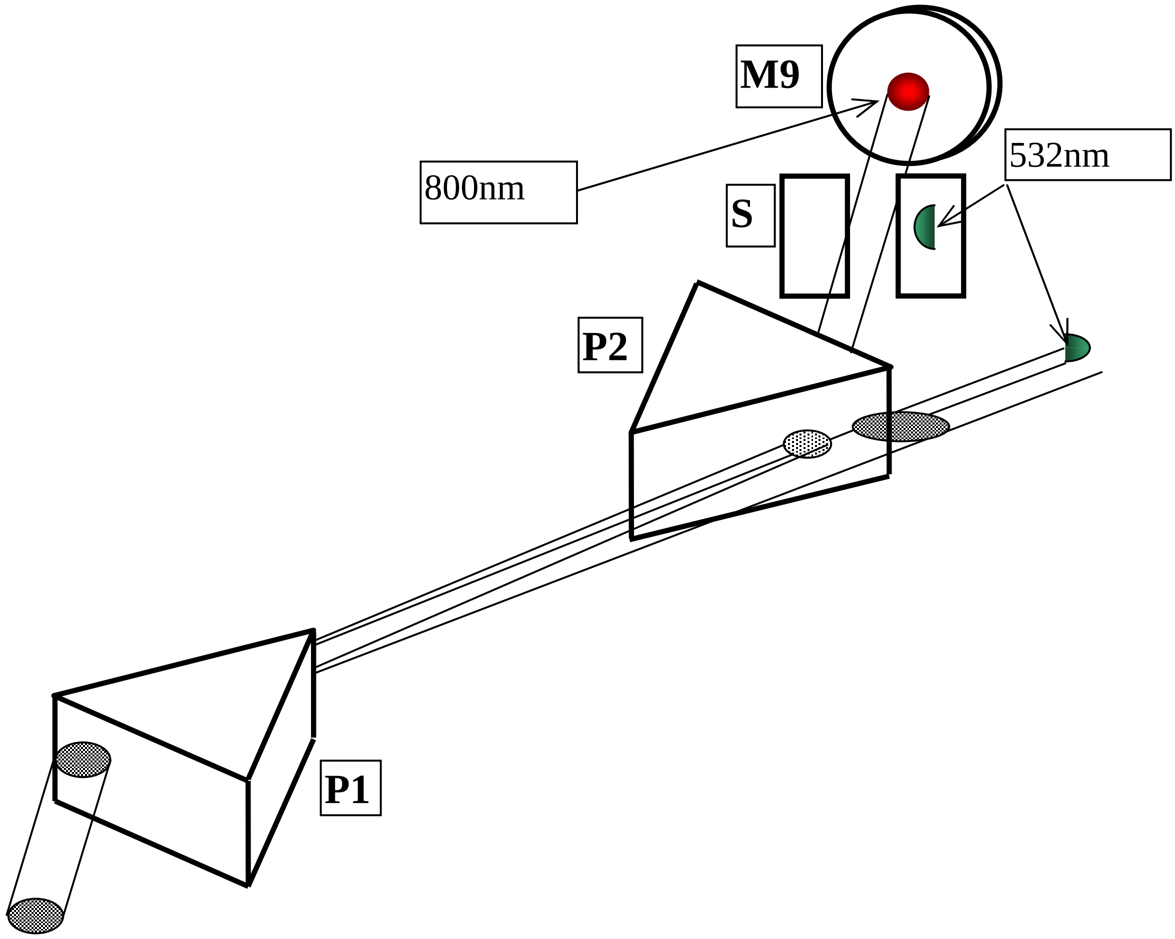


Figure 10. Beam positions on prisms and slit.

Note. It's recommended to do spots positions of pump and Ti:Sapphire laser lasers radiation on the prisms (P1, P2) and slit (S) for femtosecond generation as shown on picture 10.

63. Align P1 so that generation is passing almost through the apex of prism. But generation should not be lost. (About 1-2 mm from apex)

64. Test the output beam using fast photodiode and oscilloscope.

65. Using the position aligning screw remove P2 from the pump beam. The generation will be lost.

66. Move by micrometric screw (*or use motorized slit and prism control buttons)* and slightly push fixating screw of a prism P2 by your finger (thus you change the depth of insertion of the prism). Look at the result on the oscilloscope. Then moving M2 by small steps find the place where the pulses appear. Femtosecond pulses should appear near the end of the region of stability. Continuous pulse train should be observed on the oscilloscope screen in femtosecond operation.

Note*: don't push prism P2 with a force.*

Note*: We remind you that two regions of stability exist in asymmetric cavity. You are moving through the stability region having less distance between M1 and M2 (102-105mm).*

67. Find the position where pulse train is observed while you hold the prism in place. Then align the prism position micrometric screw (*or use motorized slit and prism control buttons)* to hold the prism in place.

68. Measure the spectrum of Ti:Sapphire laser radiation with the help of a spectrometer or a diffractive grating.

69. Measure the spectrum and try to find its optimum using control of P2 mount. You will obtain shorter pulses with broader spectrum. Spectral bandwidth should not be less than 14 nm at FWHM (full width half maximum) with central wavelength at 800 nm. This corresponds to 50 femtosecond pulse length.

70. Femtosecond operation starts from moving of optical elements. Once started, femtosecond operation should last for hours at good pump laser stability and in stable room conditions. When femtosecond operation disappears, start it again with mechanical movement of P2. (Press the Starter button *or turn on the Electronics module*).

71. Measure pulse duration with an autocorrelator.

72. To get a tuning of output wavelength and to control spectral bandwidth, flip the slit back into its place. Align the width and position of the slit so that the pulses easily appear at the same spectral position where they appeared without the slit. Write down the position of the prism and the slit. Then watching the spectrum and "pulse train" move the slit to shift the pulse spectrum to the desired region. (In versions with combined prism and slit unit move the prism position only the position of the slit will change also). Verify that laser easily starts at new position. Repeat this steps until you reach the desired central wave length.

If you failed to achieve the lasing after several attempts, please repeat all the steps, including the italicized ones.

7. DAY-TO-DAY OPERATION

1. Switch on cooling water for Ti:Sapphire laser (moderate flow).

2. Switch on the pump laser (3-5 W output).

3. Ti:Sapphire will give proper characteristics after 30 minutes if you use standard pump laser or after 20 min. with "Beam-Lock" Ar-ion lasers. Pump power should be stable from day to day.

4. Small adjustments of M9 and OC might be necessary in day-to-day operation

5. To turn off the system repeat the procedure in reverse order.

Note: Occasionally, it may be necessary to clean the optics and surfaces of the Ti:Sapphire crystal. The best method for cleaning the surfaces is to first block the pump laser beam and then blow excess particles from the surface. Then fold a piece of lens tissue into a pad and clamp with a hemostat (usually provided with the pump laser). Soak this pad with spectroscopic grade acetone or methanol, and shake off the excess liquid. Then make ***!one cleaning stroke only!*** *across the surface (particles on the surface can become imbedded in the tissue and act as an abrasive if a second stroke is made across the surface).*

8. POSSIBLE PROBLEMS

1. Pump laser output is not TEMoo mode.

2. Pump laser is not stable enough.

3. Optical surfaces of the laser elements are dirty.

4. Alignment steps were not performed correctly to reach good femtosecond pulses. Please repeat the alignment. Proper alignment of the Ti:Sapphire femtosecond laser can seem more like an art than science. Stick with it. After a few hours of work you will start to get a feel for the configuration preferred by your laser. Once the full alignment is made, and the laser has not been moved, none or minor adjustments are further required.

NOTE: *Pulses shorter than 50 fs were obtained with this laser. However, optimization of femtosecond operation takes time and requires patience. This laser is optimized at 3W-5W.*

9. ELECTRONICS MODULE (Version LS-6.0)

Electronics module LS-6.0 is intended for continuous monitoring of optical signal of mode-locked lasers and disturbing the resonator on case of mode-locking regime felt down.

LS-6.0 consists of a photodiode (Fig. 5.1) powered from the voltage regulator, resonant amplifier, detector, watch-dog timer, one short pulse generator and output driver. Detector output is proportional to first harmonic component amplitude of input optical signal. Central frequency of bandpass filter could be adjusted in the range of 80 - 120 MHz. If detector output is lower than the threshold value for a period longer then 100 ms, single output pulse will be generated. If there is no optical signal on detector, the LS-6.0 will not disturb the resonator.

Pulse amplitude and, consequently, resonator disturbance degree could be adjusted to provide a reliable and smooth mode-locking start-up. Output driver provides 12 V peak output for electromagnetic actuator. RF service output (BNC female connector, 50 Ohm) could be used for monitoring of a photodiode output *(!please note that BNC connector must always be loaded with 50 Ohm or connected to the oscilloscope!)*

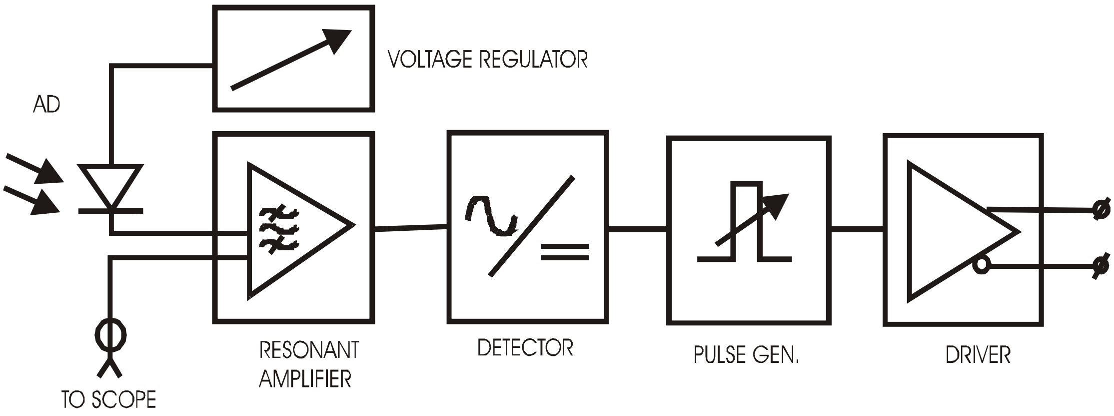


Figure 5.1

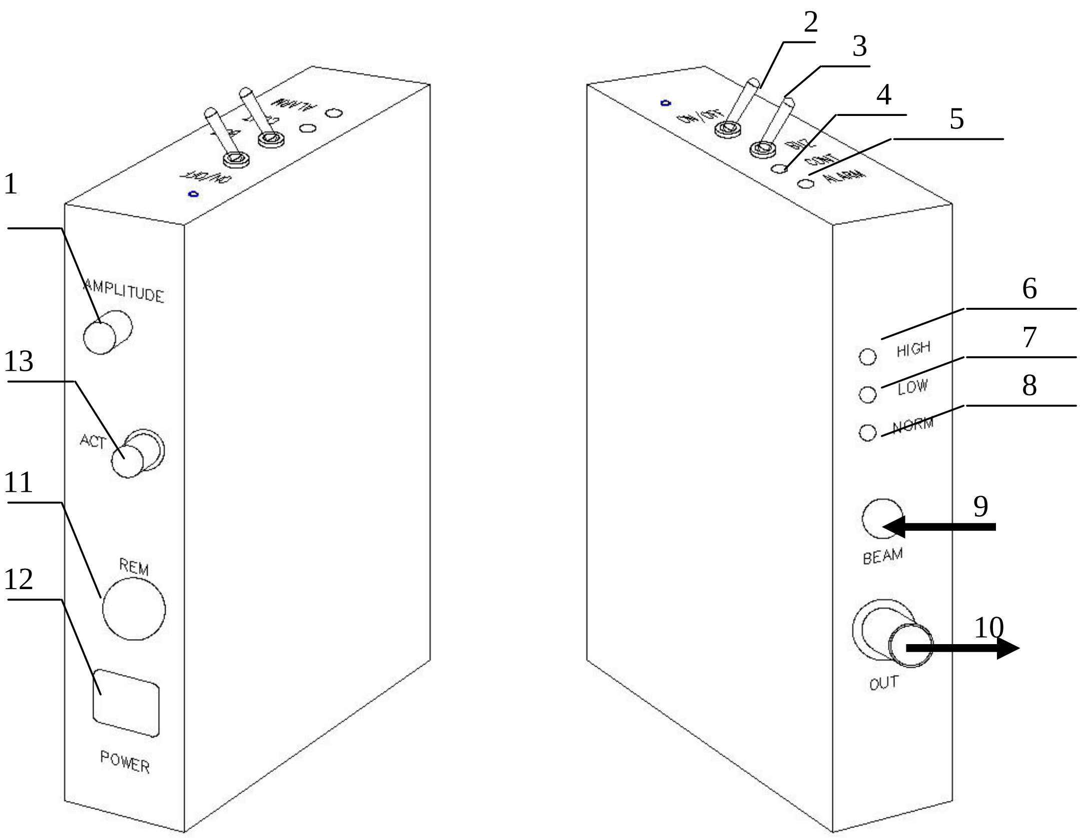


Figure 5.2

1. “AMPLITUDE” is used for setting the amplitude of output signal (amplitude of mechanical fluctuation).
2. “ON / OFF” - pulse enable switch. When OFF, no output pulse will be produced. If ON, the “CONT” led is on. The signal will be generated if there is no pulse regime. The signal will not be generated if there is no optical signal on photodiode.
3. “BUZ” - Beeper enable switch. Enables sound signal (short beeps) during absence of optical pulse train.
4. “CONT” - green LED "PULSE ENABLE". Indicates actuator driver output enable.
5. “ALARM” - Red LED “ALARM" Indicates an absence of input pulse train (only CW regime).
6. “HIGH” – Red LED. Led is on if the optical power on the photodiode is too high.
7. “LOW” - Yellow LED. Led is on if the optical power on the photodiode is too low.
8. “NORM” – green LED. Led is on when the optical power on the photodiode is normal.
9. “BEAM” - optical beam input. A light spot should be pointed at the center of the photodiode substrate. Sensitive area size is about 1 x 1 mm. Adjust beam position of monitoring signal by a scope.
10. “OUT” - 50-Ohm BNC connector. Photodiode signal output - to oscilloscope *(!please note that BNC connector must always be loaded with 50 Ohm or connected to the oscilloscope!)*.
11. “REM” -«EXT» - remote status connector. Output optoisolated FET switch is on during absence of optical pulse train (fig. 5.3).

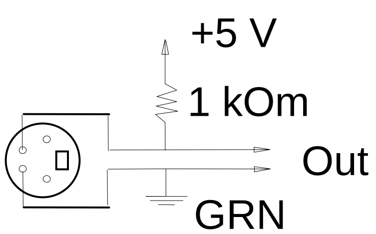


Figure 5.3

Note. When in CW regime the "out" is "high". When pulses regime or there is no generation at all the "out" is "low".

12. "POWER" - Power supply connector
13. "ACT" - Driver output connector - to actuator.

INSTALLATION AND ALIGNMENT

1. Place and fix your LS-6.0 on the optical table (Fig 5.4).
2. Connect a pulse prism actuator to LS-6.0 using driver output cord.
3. Get femtosecond operation of the laser.
4. Connect the LS-6.0 to DC power supply (+ 15V).
5. Direct a part of output radiation (**≤10 mW**) to the photodiode of the LS-6.0. At suitable level of light, the green LED "Normal" is on (8 in Fig 5.2).
6. Connect the 50-Ohm BNC connector (10 in Fig.5.2) of the LS-6.0 to a 400 MHz oscilloscope.
7. Amplitude of the oscilloscope signal should be about 0.1 V. Use additional lens to focus radiation to photodiode if necessary.
8. Switch on pulse-enable switch (2 in Fig.5.2). Green LED "control" (4 in Fig.5.2) lights on.
9. Rotate amplitude adjust (1 in Fig.5.2) clockwise (i.e. maximize deviation of prism).
10. Cross beam inside the cavity for a short period. Femtosecond operation should appear in a few seconds after that.
11. By adjusting the prism deviation select the best value for femtosecond start.

Attention! LS-6.0 controls femtosecond operation only at occasional failures. It cannot start mode-locking with unaligned resonator.

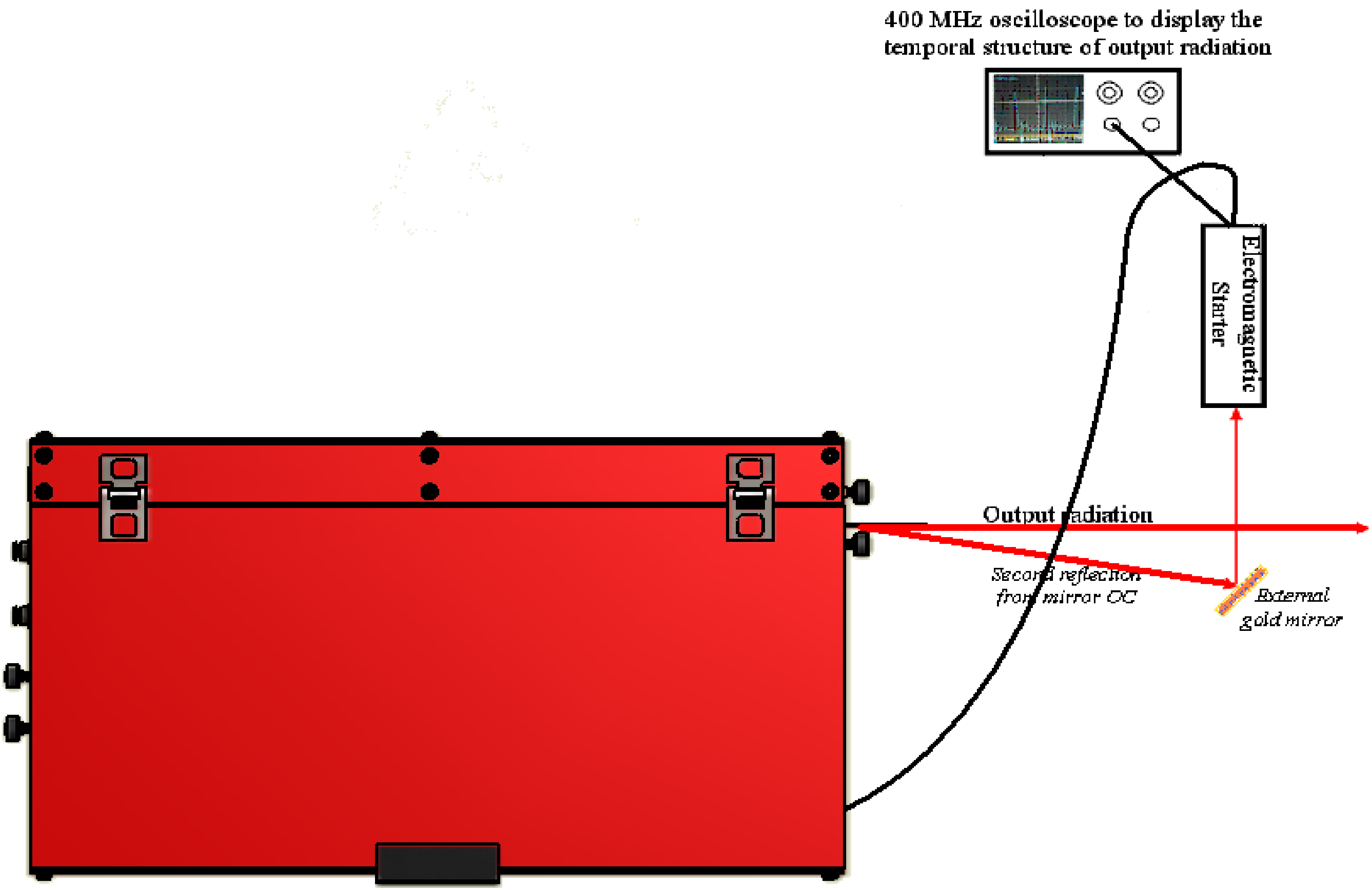

400 MHz oscilloscope to display the
temporal structure of output radiation
Electromagnetic
Starter
Output radiation
Second reflection
from mirror OC
External
gold mirror

Figure 5.4

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